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BY

NORMAN ABRAMSON AND EUGENE R. CACCIAMANI, JR.







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Norman Abramson
The ALOHA System
University of Hawaii
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Eugene R. Cacciamani, Jr.
American Satellite Corporation
Germantown, Maryland



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## Abstract

In this paper we provide a survey of the history, technology and economics of commercial satellite data communications. Technological and economic trends in satellite data communications are examined, and the differences between the satellite channel and terrestrial channels are emphasized. After a discussion of existing standard tariffed satellite data services and special tariffed data services we list some possible future data services which might be offered to take advantage of the special properties of satellite data channels.

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## 1. HISTORY

The commercial use of communication satellites began with the successful launch of INTELSAT I in April 1965. INTELSAT consists of a consortium of more than 80 member countries which operates a network of geostationary communication satellites positioned over the Atlantic, Pacific and Indian Oceans. Since each satellite covers approximately one third of the surface of the earth such a network is adequate for almost complete earth coverage. Since 1965 INTELSAT has designed three new generations of communication satellites; the latest, INTELSAT IV, was first put into operation in March, 1971.

In addition to the INTELSAT system several national or regional communication satellite systems have been or soon will be launched. By early 1975, five other systems were operational -- Molniya (USSR), Anik (Canada) and Westar (USA) -- with their own satellites, and RCA and American Satellite Corporation employing the Anik and Westar satellites for their space segment. Other communication satellites expected to be launched during this decade are two additional U.S. systems (in competition with Westar), a European system involving nine nations, an Iranian system, a Japanese system, an Arabian system, an Indonesian system (perhaps involving Malaysia and the Philippines), a Brazilian system and an Indian system. An international maritime communications satellite (MARISAT) is scheduled for launch early in 1975, and an international aeronautical satellite (AEROSAT) for the late 1970's.

In 1975 the pace of development of communication satellite systems seems to have accelerated markedly. For example NASA successfully launched three commercial communication satellites from Cape Kennedy during 1974 [1] while during 1975, from 8 to 10 such launches are anticipated. Each of these satellites, with a capacity of about 10,000 telephone circuits over intercontinental distances, will have a significant impact on the existing patterns of communication traffic. For example the planned European Communication Satellite System will be designed to carry up to one half of the European telephone traffic between cities more than 800 km. apart [2].

## 2. THE TECHNOLOGY OF COMMUNICATION SATELLITE SYSTEMS

A satellite in a circular orbit around the earth will have a period which varies from about 1.5 hours at an altitude of 1000 km. to about 100 hours at 100,000 km. At an altitude of 36,000 km. a satellite in a circular orbit will have a period of 24 hours. If such a satellite is placed in orbit over the equator it will appear stationary from any point on the earth. Such a satellite is called geostationary. Three geostationary satellites positioned at roughly equidistant points around the equator are sufficient for essentially full earth coverage.

Geostationary satellites are employed as radio repeaters for communication purposes. A signal from one earth station is transmitted up to the satellite (the uplink) and the signal is retransmitted down from the satellite to another earth station (the downlink). In order that the signal transmitted by the satellite not interfere with the signal received by the satellite, the uplink and the downlink signals use different frequency bands. Most of the present generation of geostationary satellites use the 4000 MHz band for the downlink and the 6000 MHz band for the uplink.

Table 1 gives some physical characteristics of the INTELSAT series of satellites and illustrates clearly the rate of progress in the development of such systems.

| INTELSAT | PRIMARY USAGE YEAR | DIAMETER (cm.) | HEIGHT (cm.) | WEIGHT (kg.) | BANDWIDTH (MHz) | DC POWER (watts) | EFFECTIVE RADIATED POWER (watts) | NUMBER OF TELEPHONE CIRCUITS |
|---|---|---|---|---|---|---|---|---|
| I | 1965-67 | 72 | 60 | 39 | 50 | 33 | 20 | 240 |
| II | 1967-68 | 143 | 68 | 86 | 130 | 75 | 35 | 240 |
| III | 1968-71 | 143 | 105 | 151 | 225 | 125 | 300 | 1200 |
| IV | 1971-78 | 240 | 532 | 721 | 432 | 500 | 2400 | 6000 |

Table 1. PHYSICAL CHARACTERISTICS OF INTELSAT SATELLITES [3]

Since the characteristics of most commercial satellite channels match the classical Shannon model of a channel with additive white Gaussian noise quite well, we may calculate the channel capacity by means of the Shannon formula

$$C = W \log \left(1 + \frac{S}{N}\right)$$

where C is the channel capacity in bits per second, W is the channel bandwidth in hertz and S/N is the signal-to-noise power ratio at the receiver. From this equation we see that the capacity of a satellite to transmit messages depends upon both the bandwidth available and the total effective radiated power of the satellite. But the capacity increases rapidly with the bandwidth while increasing much more slowly with the radiated power. The upper limits of bandwidth available in the 4 GHz and 6 GHz bands assigned to communication satellites have been reached in present systems, and additional bandwidth will only be obtained by shifting to higher frequencies -- frequencies which may require more expensive equipment. The effective radiated power however can be expected to increase in the next generation of communication satellites. As noted above, while this will not lead to large increases in satellite capacity, it will lead to a dramatic decrease in the size and complexity of ground systems necessary to receive satellite signals and it will lead to greater flexibility in satellite communication systems architecture.

Since INTELSAT I almost all of the more than 80 earth stations used in the INTELSAT system have included (a) a 30 meter diameter antenna (b) sophisticated tracking and control equipment to point this large antenna and (c) extremely sensitive cooled receivers to detect the weak signal from the satellite. While such ambitious earth stations may have been desirable for use with INTELSATs I, II, and III, they seem overdesigned for use with INTELSAT IV and its successors.

Earth stations designed for use in satellite systems put into operation in the early 1970's generally employ simpler uncooled amplifiers and smaller diameter antennas -- typically 10 to 15 meters. The European system plans to employ antennas with diameters no greater than 15 to 18 meters, and it seems likely that most earth stations in that system will have even smaller diameter antennas. As the diameter of an earth station antenna is decreased the beamwidth of its radiation pattern increases thus leading to the possibility that the signal transmitted to one satellite may interfere with the signal to an adjacent satellite. At the presently planned spacing of geostationary satellites around the equator it appears that this may limit the minimum antenna diameter to from 3 to 5 meters for the 6000 MHz band now used.

A final but most important set of properties of communication satellites is related to the differences between satellite and cable telephone channels [4]. Satellites are used almost interchangeably with land lines and cables in the present day worldwide telephone network. In particular commercial satellite channels are employed as point-to-point links between two earth stations, just as if these stations were linked by a direct cable connection. But a satellite is not just a big cable in the sky; a single satellite channel has a broadcast character which allows it to transmit and receive signals from any earth station in its antenna pattern. This flexibility provides the satellite communication channel with particularly powerful capabilities for use in a digital network composed of a large number of small earth stations [4]. If a destination address is attached to each message transmitted by an earth station in such a system, then it is no longer necessary to devote a separate channel to each pair of earth stations which wish to communicate. Once this flexibility is appreciated it becomes possible to employ novel forms of communication systems architecture such as SPADE [5] to dynamically allocate voice circuits (in seconds), or packet broadcasting [6] to dynamically allocate data packets in microseconds.

Generally speaking, more reliable data channels can be achieved using satellite systems. This is particularly true if the service can be provided directly to the user without intervening terrestrial carrier links. Since the system consists of a single transponder the channel characteristics are well known and can be controlled within certain limits. Unlike terrestrial circuits, which can experience fading due to microwave propagation path anomalies as well as "bursty errors" due to telephone exchange equipment switching, the satellite circuit is approximately a Gaussian channel. Hence performance can be controlled by adjusting earth station transmit power, and further performance enhancement can be achieved using forward error correction techniques [7,8].

## 3. THE ECONOMICS OF COMMUNICATION SATELLITE SYSTEMS

Perhaps because it is figuratively the most visible part of a satellite communication system the cost of the satellite is often thought to be the dominant cost in the total system. In fact, the total cost of satellite communication is composed of three separate components -- and in the present generation of satellites the cost of the satellite itself is rapidly becoming the smallest of these components. The three components of the total cost are (a) the satellite cost (b) the earth station cost (including multiplexing equipment) and (c) the cost of distribution from the earth station to the user.

*(a) satellite cost*

Cost estimates for the space segment of a single full duplex voice channel in the INTELSAT series of satellites have been provided by Roberts [9].

| *INTELSAT* | *PRIMARY USAGE YEAR* | *NUMBER OF VOICE CIRCUITS* | *LIFETIME (years)* | *TOTAL COST (million $)* | *COST PER VOICE CIRCUIT PER YEAR ($)* |
|---|---|---|---|---|---|
| I | 1965-67 | 240 | 1.5 | 8.2 | 22,800 |
| II | 1967-68 | 240 | 3 | 8.1 | 11,300 |
| III | 1968-71 | 1200 | 5 | 10.5 | 1,800 |
| IV | 1971-78 | 6000 | 7 | 26.0 | 600 |

Table 2. INTELSAT COST ESTIMATES [9]

Comparable cost for the Anik or the Westar satellite is about $300 per voice circuit per year.

From the point of view of satellite communication systems, digital transmission systems (such as SPADE and TDMA) [5,10] are generally more efficient in transmitting voice and data than traditional analog FM/FDMA systems. Further, in transmitting data, the satellite digital voice circuit is the equivalent of at least six voice circuits in a conventional analog transmission land line system. Up to 64,000 bits per second of digital data can be transmitted over the equivalent satellite digital voice channel, while a single conventional circuit may achieve a data rate of 9600 bits per second under carefully controlled conditions [8]. A 50,000 bits per second data circuit, tariffed comparable to a single voice channel and operating over the Pacific Ocean INTELSAT IV satellite, has linked THE ALOHA SYSTEM in Honolulu with the ARPA Computer Network in North America and Europe since December, 1972 [11].

*(b) earth station cost*

The cost of an earth station for a satellite communication system is more difficult to determine than the cost of the satellite. In analyzing the cost of an earth station it is necessary to specify the communication capabilities desired of the station. For example, almost all the stations first built in the INTELSAT system were capable of transmitting and receiving color television signals while simultaneously handling voice and data traffic. Furthermore they were designed to have this capability with satellites transmitting considerably less power than the current generation of satellites. As mentioned earlier these earth stations typically consist of a thirty meter antenna, cryogenically cooled receivers and tracking capabilities of questionable utility. The cost of such an installation has been from about \$3,000,000 to \$5,000,000. The cost estimates for the smaller and simpler earth stations used in the Canadian and U.S. domestic systems have been from \$1,000,000 to \$2,000,000 for full television and voice-data capabilities. If we consider earth stations with only data communication capabilities then even simpler installations are possible [12]. Earth stations have been installed by U.S. domestic satellite carriers for specialized data applications ranging from \$100,000 to \$400,000 per station, and future stations at even lower costs are projected.

Some of the factors that contribute to the lower cost earth station installations include: smaller diameter antennas, uncooled low noise receivers, low power transmitters and simplified communication hardware requirements. In many instances forward acting error correction techniques can be effectively added to the system at little additional cost providing significant improvement in performance [7,8]. Earth station parameters can be adjusted to provide a cost effective earth station based on capital investment in the earth station and recurring space segment charges.

Two other factors that significantly impact earth station cost include equipment redundancy requirements and receive-transmit only earth stations versus duplex operating earth stations. Redundancy implies that additional components are implemented to provide back-up in the event of failure of on-line components. User reliability requirements will determine the need for redundancy. For example, assuming unmanned earth station operation, the expected reliability of a non-redundant earth station is 99.4% versus 99.9% for a redundant system. However, the cost of adding redundant components can amount to a significant portion of the total earth station cost; as much as 40% of the total cost of a simple single data link earth station. Thus the user must be careful not to overspecify his reliability requirements.

Again user requirements will define the earth stations to be duplex or simplex operating. A simplex operating earth station requires correspondingly less equipment than does the duplex station and hence is less costly. A typical example of a simplex operating system could be a point to multi-point newspaper publishing system whereby the paper is distributed from a central point to a number of printing plants equipped with receive-only terminals. Television and radio distribution networks would be another example of a simplex earth station network.

Further simplification in earth station design for data communications can be achieved by reduced multiplexor requirements. In some cases this function (when required) can be replaced by a program in the computer connected to the earth station [4,5]. This latter possibility is particularly attractive because of the flexibility and added capability of a computer network employing packet broadcasting architecture.

Further decreases in costs, beyond those discussed in this paper, can be projected for newer generation satellites as well as for present generation satellites utilizing newer data transmission-multiplexing techniques.

*(c) ground distribution cost*

General distribution earth stations can require extensive ground interconnection circuits to reach the user. This is particularly undesirable to the data user since it can add significantly to the overall service cost.

For many small data terminal earth stations, however, it is possible to co-locate the earth station at the user's premise, thus reducing the ground interconnect costs to zero and insuring high end-to-end performance. American Satellite Corporation has recently installed a "dedicated user" data network where all stations are co-located at the user's premises and the overall bit error probability is nominally less than $10^{-8}$ for 1.344 megabits per second data service [13].

## 4. EXISTING SERVICES

In today's environment there exist essentially two types of satellite data services. The first consists of tariffed service offerings of more or less standardized circuits that a user can order from an existing "shopping list", while the second consists of specialized tariff services.

Usually long haul service provided by satellite is more c

than comparable service provided by purely terrestrial links.

true of specialized higher data rate services. Today there is

terrestrial capacity available to provide long haul transmissi

rates of one million bits per second and higher. To provide n

these rates in most situations will require large inflexible i

new construction of terrestrial facilities which will require

tion times. Satellite systems can be quickly and inexpensivel

establish circuit connections wherever the user desires and at

that he needs.

The ability and willingness of the satellite carriers to

new services to meet evolving user requirements previously not

using terrestrial lines is of considerable importance to the c

communication services. Specialized tariff services can be de

as requirements arise, and specific tariffs can be filed to co

specific applications on a case by case basis.

*(a) tariffed services*

Both the U.S. domestic carriers and INTELSAT offer a vari

tariffed services. COMSAT, as the U.S. representative to and

acts as a carrier's carrier, providing satellite circuits to t

tional Carriers, interfacing with them at the COMSAT operated

Services in operation today include video transmission on dema

circuits using both pre-assigned FM/FDMA transmission and the

assigned digital transmission system; teletype, telex, voice b

9600 bits per second and digital data circuits operating at 50

bits per second.

The U.S. domestic carriers, American Satellite Corporation, Western Union and RCA, interface at the user premises either using terrestrial interconnections from their respective earth stations to the user's facility or, in specialized cases, locating their earth station at the user's premises.

Representative tariff rates for domestic services are shown in Table 3 and the trend of INTELSAT satellite tariffs over the last few years is shown in Table 4. The three different rates shown in Table 4 give the rates INTELSAT charges COMSAT, the rate COMSAT charges the U.S. carriers and the rate the U.S. carriers charge the customer.

| *Between* | *and* | *Satellite Single Channel Rates* | *AT&T Single Channel Rates* |
|---|---|---|---|
| Chicago | New York | 620 | 725 |
| Chicago | Los Angeles | 820 | 1598 |
| Dallas | Los Angeles | 820 | 1175 |
| New York | Los Angeles | 1120 | 2197 |
| Washington | San Francisco | 1120 | 2188 |

Table 3. REPRESENTATIVE U.S. DOMESTIC TARIFFS IN FEBRUARY 1975
(satellite, ground links, and local loops)

*(b) specialized tariffed services*

A major effort of some of the U.S. domestic carriers has been to respond to requests for new service requirements that had previously remained unsatisfied. In general, these services result in a mutually beneficial contract between the user and the carrier and a special tariff, covering this service, is then filed with the U.S. Federal Communications Commission.

| INTELSAT | | COMSAT | | CARRIERS | |
|---|---|---|---|---|---|
| *Effective Dates* | *Monthly Half Ckt. Rates* | *Effective Dates* | *Monthly Half Ckt. Rates* | *Effective Dates* | *Monthly Half Ckt. Rates* |
| 6/27/65 | $2,667 | 6/27/65 | $4,200 | 6/27/65 | $10,000 |
| 1/1/66 | 1,667 | 4/4/67 | 3,800 | 10/1/66 | 8,000 |
| 1/1/71 | 1,250 | 7/1/71 | 2,850 | 10/1/67 | 6,500 |
| 1/1/72 | 1,080 | | | 8/1/68 | 6,000 |
| 1/1/73 | 930 | | | 4/1/70 | 4,750 |
| 1/1/74 | 750 | | | 8/15/71 | 4,625 |

Table 4. HISTORY OF SATELLITE RATES - U.S. TO EUROPE

**NOTE:** Carrier, COMSAT and INTELSAT rates are for circuits to the mid-point (i.e., half-circuit rates). Historical information with respect to foreign charges from mid-point to ultimate destination is not easily available. Carrier rates include terrestrial haul from COMSAT earth station to New York.

Three examples are (a) a five earth station dedicated user data network installed by American Satellite Corporation in 1974 to serve the U.S. Government, (b) a dedicated broadcast network to be installed by American Satellite in 1975 for the Dow Jones Company to transmit the Wall Street Journal, and (c) oil exploration ship terminals to be installed by Western Union and General Electric Company to serve EXXON.

The government network installed by the American Satellite Corporation consists of five dedicated user earth stations on the government's facilities. The system is used to transmit and receive five 1.344 megabit data streams over long and medium range distances to connect remote data collection terminals to a primary computer facility.

The Dow Jones service will enable digital broadcast distribution of the Wall Street Journal to remote printing plants for regional distribution. The initial service will be at 150,000 bits per seconds and combined with Dow Jones' provided facsimile data compression equipment, a complete "master" newspaper page can be transmitted in about three minutes. Eventually, when the system data rate is increased to 1.344 megabits per second, the transmission time will be about one minute per page.

The Western Union service will consist of gyrostabilized tracking antennas on board EXXON oil exploration ships. The stations will provide both voice and data lines to EXXON's central computer located in Houston, Texas.

## 5. FUTURE SERVICES

With the hindsight provided by ten years since the launch of INTELSAT I it is easy to forget the revolutionary nature of this new telecommunications medium. And it is easy to forget the uncertainties which existed prior to 1965 concerning the suitability of geostationary communication satellites for incorporation into the existing telecommunications plant. In view of these uncertainties, it was natural to try to view the channel capacity provided by the new telecommunications medium as a replacement for other channels and it was natural to minimize the differences between satellite channels and other channels (see Section 3). For the first ten years therefore, the satellite channel has been used almost exclusively as a replacement for cable or microwave channels. This situation appears to be changing as the differences of satellite channels are more generally recognized and as these differences are considered in the context of the new national, regional and special purpose satellite systems now being launched.

The differences we have mentioned may be reflected in video and voice circuits, but because of the greater flexibility of digital data, the impact of the unique properties of satellites will be most visible in a number of proposals for satellite data communication systems providing unconventional services. In the United States approval for such unconventional data communication services will be necessary from the Federal Communications Commission. But this agency has indicated that it is receptive to proposals which take advantage of the properties of satellite channels.

The common themes of all of these proposals for unconventional data communication services by means of satellites may be described as dynamic resource allocation, broadcast capability and (its dual) multiple-access capability. We will briefly describe a few such services in the remainder of this article.

*(a) MARISAT and AEROSAT*

The ability to dynamically allocate satellite channel capacity among a number of mobile stations is exploited in the planned MARISAT and AEROSAT systems. The first MARISAT satellite is scheduled for launch in 1975 and will be employed for voice and data channels to ships in the Atlantic using

L-band frequencies (1.6 Ghz). MARISAT will be operated by COMSAT and will initially provide only one voice channel and 44 teletype channels.

An interesting feature of the MARISAT program is that during the first few years of operation much of the satellite channel capacity will be employed in a separate U.S. Navy communication network employing the UHF band (240-400 Mhz). As the civilian maritime needs increase the satellite power will be shifted from the UHF transmitter to the L-band transmitter in the satellite and when the Navy has completely phased out its use of MARISAT the capacity available to the civilian maritime system will be nine times the initial capacity. The precise allocation of this capacity among voice, teletype, and other data channels will depend upon the experience of the system during the first few years. This planning flexibility is of course a major advantage of satellite communication systems.

In December 1974, an agreement to establish an aeronautical satellite capability was signed by ESRO, COMSAT and the Canadian government; by an earlier agreement the U.S. Department of Transportation and the Federal Aviation Agency have agreed to participate in the AEROSAT program. The first AEROSAT launch is expected before 1980.

*(b) scheduled channel sharing*

The MARISAT and AEROSAT services provide an example of "demand access", or unscheduled sharing of the satellite space segment portion of a communication system. It is also possible to design special data communication systems which share the space segment in a scheduled manner. For example a banking or credit card system might be designed with small earth stations located at each of ten or twenty regional centers and the centers might transmit financial data to a national center on a regularly scheduled basis over the same channel. A scheduled channel sharing service might also be attractive in situations where data is gathered on a daily basis by geographically dispersed units -- for example, oil exploration ships -- and then transmitted to a central processing facility.

Land lines or microwave systems could also be used for such systems of course, but a satellite data service has certain properties which can make it more attractive. A land based system will usually have to locate the central processing facility near the geographical center of the system in order to minimize leased or dial-up line charges. In a satellite system the central facility can lie anywhere within the antenna pattern of the satellite. In addition the data transmitted from the outlying units may be rerouted to a backup central facility with a minimum of effort, even if the backup facility is located at some distance from the primary center.

The earth station cost versus space segment cost tradeoff of a scheduled channel sharing satellite data service is different from the tradeoff in the case of conventional fixed point to fixed point satellite channels. Since there are many earth stations making use of the same satellite channel resources, the earth stations may tend to be small, inexpensive and profligate with satellite channel capacity in order to minimize the total system sost. In fact, as the number of possible nodes in such a satellite data communication network increases (and as the fraction of the satellite capacity used by each node decreases) the overriding consideration in the system design becomes the design of the many inexpensive earth stations of the network.

*(c) digital broadcasting*

All of the systems discussed so far employ the traditional point-to-point architecture of ground based data communications, although the receive or transmit points may be reconfigured in order to fully utilize the space segment. But as we pointed out, a satellite is basically a broadcast communications medium, connecting any point in its electromagnetic view to all other points. This property may most easily be exploited in the distribution of identical data from one point to several other points. Examples of such systems are in news or financial wire services or in the distribution of national newspapers or magazines to regional printing plants -- or even plants located in individual cities. A fully redundant earth station employing a five meter dish with receive only capabilities at a data rate of 1.344 bits per second could be built at a cost of about $150,000. At this data rate, it takes only one minute to transmit one newspaper page. The advent of such a nationwide system could very well lead to a few nationwide newspapers with separate sections produced in each city for local news.

*(d) packet broadcasting*

As described above digital broadcasting provides a natural method of transmitting data from one to many earth stations. It is a relatively small step from this concept to packet broadcasting. A method of operation which allows efficient transmission of data from many earth stations to one earth station, or even from many to many. Certain kinds of data communication systems operate under extreme conditions of traffic variability. For example terminal time sharing networks, data base inquiry systems (e.g., airline reservations, stock market quotations), and computer networks with file transfer capabilities all tend to operate with high peak to average data rates.

In these situations it is possible to allow each earth station in the data network to share a single high capacity satellite channel [5,9]. Data is buffered in each earth station to form packets (typically 1000 bits in length) and each packet together with a header containing address and control information is transmitted over the commonly shared satellite channel at the maximum rate of the channel. In such a packet broadcasting data network it is not necessary to control or synchronize the burst transmission from the separate earth stations. The packet header of each packet is received by all the earth stations in the system and the packet is accepted by that station (or stations) with the proper address. If the average data rate of each station is low enough, and if there are not too many earth stations the probability that two packets will be transmitted at the same time (and thus interfere with each other) will be low. If such interference does occur however the two earth stations which transmitted the packets can detect the interference since, in a satellite channel, it is possible to monitor your own transmission. Each station can then repeat the lost packets until a successful transmission occurs.

Packet broadcasting systems are an attractive possibility from the point of view of efficient use of space segment satellite resources, since the satellite transponder need only provide power during the short burst when it is transmitting a packet. Thus a satellite transponder operating in a packet broadcasting mode at a duty cycle of 10% would only transmit 10% of its rated power; alternatively such a transponder could be adjusted to provide 10 db more power during its transmission of packets while keeping its average power output fixed. An earth station employed for packet broadcasting needs no multiplexor since the multiplexing can be carried out by a rather simple software module in the computer system receiving the data. A packet broadcasting earth station using a single transponder at a peak data rate of one megabit on a Westar class satellite could be build for about $30,000 to $50,000. Such a system could easily handle the data traffic generated by 10,000 computer terminals in a time sharing or data base inquiry system.

The cost figures for packet broadcasting earth stations we have cited above are in the same range as (or lower than) the cost of many present day peripheral devices for medium and large scale computer systems. This fact suggests the possibility that such an earth station might very well be considered to be, and marketed as, just another computer peripheral device by a large computer manufacturer. And in the 1980's when ordering a large scale computer, one may very well be asked to consider system configurations which include a packet broadcasting earth station with a 5 meter antenna on the roof of the Computer Center.

## REFERENCES

[1] ELECCION, MARCE: "Military and Aerospace," *IEEE Spectrum,* January 1975, Vol. 12, No. 1, p. 84.

[2] FALK, HOWARD: "European Satellites to 'Fly'," *IEEE Spectrum,* August 1974, pp. 55-66.

[3] ALTMAN, FREDERICK J. et al.: "Satellite Communications Reference Data Handbook," *Computer Sciences Corporation,* July 1972.

[4] ABRAMSON, NORMAN: "Packet Switching with Satellites," *AFIPS Conference Proceedings - 1973 National Computer Conference,* Vol. 42, 1973, pp. 695-702.

[5] PUENTE, J.G. and WERTH, A.M.: "Demand Assignment Service for the INTELSAT Global Network," *IEEE Spectrum,* Vol. 8, No. 1, January 1971, pp. 56-69.

[6] METCALFE, ROBERT M.: "Packet Communication," *MAC TR-114,* Project MAC, Massachusetts Institute of Technology, Cambridge, Massachusetts, December 1973.

[7] CACCIAMANI, EUGENE R. JR.: "The SPADE Concept Applied to a Network of Large and Small Earth Stations," *Communication Satellite for the 70's; Technology,* edited by N.E. Feldman and C.M. Kelly, M.I.T., Vol. 25, 1971, pp. 559-572.

[8] CACCIAMANI, E.R. JR.: "The SPADE System as Applied to Data Communications and Small Earth Station Operation," *COMSAT Technical Review,* Vol. 1, No. 1, Fall 1971, pp. 171-182.

[9] ROBERTS, LAWRENCE G.: "Data by the Packet," *IEEE Spectrum,* Vol. 11, No. 2, February 1974, pp. 46-51.

[10] PUENTE, J.G., SCHMIDT, W.G., and WERTH, A.M.: "Multiple Access Techniques for Commercial Satellites," *Proceedings of the IEEE,* Vol. 59, No. 2, February 1971, p. 225.

[11] CACCIAMANI, E.R. JR.: "Synchronization and Coding in Data Communications Satellite Networks," *Proceedings of the NATO Advanced Study Institute on Computer Communication Networks,* F.F. Kuo and R.L. Grimsdale, co-editors, Noordhoff International Publishing Co., September 1973.

[12] DUNN, D.A. and ERIC, M.J.: "The Economics of Packet Switching," *Special Supplement on Computer Nets to the Proceedings of the Seventh Hawaii International Conference on System Sciences,* Western Periodicals Company, Los Angeles, January 1974, pp. 30-36.

[13] PUENTE, J.G. and CACCIAMANI, E.R. JR.: "A Dedicated-User 1.344 Megabit Satellite Data Transmission Network," *Telecommunications* (to be published in February-March 1975).